Design Document: Don't Use Dinos (DUD)

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Background

Scientific Motivation

As anthropogenic climate change prompts the global community to reduce greenhouse gas (GHG) emissions, aviation has emerged as particularly difficult to decarbonise. Continuing aviation at scale is important to the achievement of the UN's Sustainable Development Goals (SDGs), as the sector contributes significantly to hunger reduction (SDG 2) through airlifted food, and to decent work and economic growth (SDG 8) through the creation of 87.7 million jobs and $3.5 trillion in economic activity (Air Transport Action Group, 2020). Yet, its decarbonisation faces significant challenges, both regulatory, due to its international nature, and technical, as the strict requirements of flight narrow alternatives to fossil-fuels.

Aviation emissions currently primarily come from the combustion of Jet A-1 fuel. To forecast how the international aviation sector might reduce emissions while continuing to deliver societal benefit, pathways have been developed by government (DfT, 2021; ITF, 2021), climate groups (CCC, 2020; TE, 2018; Fleming et al., 2020), and industry stakeholders (Sustainable Aviation, 2020; NLR and SEO Amsterdam Economics, 2021). In addition to demand reduction and improved fuel efficiency, these pathways project that Sustainable Aviation Fuels (SAFs) and liquid hydrogen (LH2) will provide most in-sector emissions reductions for international flight, with negative emissions technologies (NETs) offsetting remaining emissions. SAFs offer identical or improved characteristics to Jet A-1 with reduced life-cycle carbon, but often require millions of hectares of land, millions of tonnes of water, and terawatt-hours of energy to fuel significant portions of flight volume. Hydrogen could offer zero point-of-consumption emissions with reduced resource requirements, but aviation technologies cannot currently accommodate it.

From a regulatory perspective, the International Civil Aviation Organization's (ICAO) Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) is the current international standard for aviation decarbonisation, but it does not require emissions reductions. Under CORSIA, airlines will only be required to offset growth in carbon emissions on international routes beyond 2020 levels after 2027, and can volunteer to offset these emissions from 2021-2026, relying on NETs to allow growth in flight volume with constant emissions (ICAO, 2021).

Sustainable development is often defined through reference to the Brundtland report (1988), which pushed meeting "the needs of the present without compromising the ability of future generations to meet their own needs," or to balancing the "triple bottom line" of societal, economic, and environmental interests (Elkington, 1994). On a global scale, environmental sustainability is often considered in relation to living within planetary limits (Lin et al., 2018; Meadows et al., 2004). Though climate change is among the most immediate of these limits, exceeding and degrading earth's biocapacity through multi-sectoral overuse of land, water, and energy resources would lead to substantial environmental and societal damages.

Though aviation is economically beneficial, its current emissions endanger its societal and economic benefits. However, in decarbonising (SDG 13), the implementation of low-carbon, but high environmental footprint, technical options will coincide with projected jumps in flight volume to significantly increase the land, water, and energy footprints associated with aviation, leading to potential conflicts between decarbonisation and other SDGs, like Life on Land (SDG 14) or Clean Water and Sanitation (SDG 6). As work from the Potsdam Institute for Climate Impact Research (PIK) and the Global

Footprint Network has highlighted, humanity's current overshoot of global resource limits is unsustainable; indicating that development and decarbonising transitions must minimize expansions of resource use (Holmatov et al., 2019).

Current aviation decarbonisation pathways, though more ambitious than CORSIA, focus primarily upon emissions reductions and its associated co-benefits while abstracting away environmental footprint concerns. The recent Jet Zero strategy consultation released by the United Kingdom's (UK) Department for Transport, for instance, dedicates two paragraphs to the sustainable sourcing of fuels upon which it pins significant emissions reductions (DfT, 2021, 27). Destination 2050, a pathway to net-zero aviation for the European Union (EU) released by aviation industry bodies, dedicates four pages to the emissions associated with land use change from Sustainable Aviation Fuels (SAFs), and includes little on minimizing or quantifying resource use (NLR and SEO Amsterdam Economics, 2021). In planning the ICAO's long-term ambitions, the ICAO has explored SAFs, carrying out a benchmarking process for induced land use change (ILUC) emissions but offering little analysis of resource consumption (ICAO, 2019).

As indicated by the many recent pathways towards decarbonization, the aviation sector is planning its climate-friendly transition. Thus, an opportunity exists to integrate environmental footprint into the industry's choices as it moves towards climatic sustainability. With a plethora of emissions-reductions scenarios plausible for the aviation industry, understanding the resource footprints associated with net zero flight systems is key to discovering most-sustainable paths.

Existing Work

An environmental footprint model for multiple AAF production pathways was developed, contributing a means of quickly evaluating the land, water, and energy use, annual emissions recaptured, and capital resource requirements associated with various aviation decarbonisation scenarios. This model can be used to quantify the environmental costs associated with different policies, technologies, and support mechanisms. Based upon the novel inclusion of feedbacks related to land, energy, water, and direct air carbon capture (DACC), new estimations were made of the environmental footprints of several fuel production pathways.

Proposed Work

Our development team proposes to address the challenges outlined in the Scientific Motivation and to improve the existing environmental footprint model by creating a new modular environmental footprint model and maintaining it on the version control site GitHub. The model is to be transcribed from MATLAB, the language in which it was originally written, to Python. Object-oriented programming approaches will be employed to create a software that is modular and more suited for future development. The team will also create a suite of tests to check the functionality of features. Finally, clear and current documentation will be generated in an automated fashion to encourage collaboration and development of additional features.

System Overview

As mentioned above, the goal of this project is to calculate the resources required for net zero emissions using an object-oriented approach with a user-friendly interface allowing for significant customization. There will be a simple GUI that requires the user to select what proportion of total fuel they want to come from hydrogen versus hydrocarbon sources; within each of these categories, the user will further specify how to divide between a number of other source types. The interface will allow for up to four layers of specification (e.g., Hydrocarbon → Biomass to Liquid SAF → Fischer-Tropsch → Switch Grass), although not all categories require this level of specificity. The program will then take the percentages given by the user and instantiate objects of each fuel type with specific values for attributes such as the energy density and amount of fuel needed. Parent classes are abstract; only the classes at the bottom of the hierarchy will be instantiated, through the factory design pattern. Each fuel will possess an environmental footprint object that holds information such as the carbon footprint to process the fuel. The last step will then be to recursively calculate the recapturing of carbon necessary to offset a given footprint (which generates its own environmental footprint) until the emissions of CO_2 fall below a specified threshold.

UML Diagram

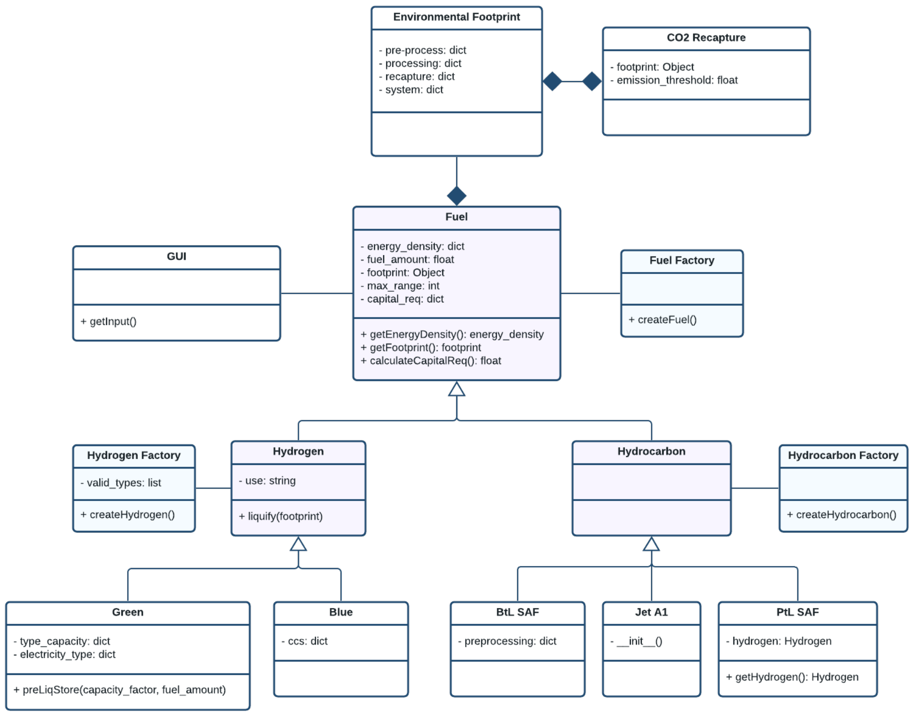

Figure 1: UML Class Diagram. Blue shading designates factories and purple shading indicates abstract class.

Timeline

A rough timeline of tasks for this project is listed below.

- Revise design document based on design review (by approx. 11/3)
- Set up Git repository and continuous integration (due 11/7)
- Start by implementing the Hydrogen branch of the class hierarchy:
  - Write "bare bones" of the factory classes
  - Write one "chain" of subclasses to make sure things work (by approx. 11/14). The easiest of these is the `Green` subclass.
  - Continue adding subclasses to expand functionality, adding to factory classes in parallel
- Implement the hydrocarbon blend branch of the class hierarchy (have at least one "chain" of subclasses functioning by approx. 11/21)
- In parallel, other members of the group will work on GUI capabilities and driver code
- Finish alpha version (due 11/30)
- Profiling, optimizations, and extensions (by approx. 12/7)

- Finish documentation and final report (due 12/14)

Responsibilities will roughly be separate as follows:

- Supervisory role - **Mike**. Since Mike knows the original Matlab code from front to back, he can help with different parts of the project as needed and make sure everything fits together. Will also be the lead writer of the final report.
- Implement the driver code and extend the GUI functionality (currently in Excel, will be rewritten in Python) - **Nick, Israel**.
- Coding of abstract classes (`Fuel`, `Hydrogen`, `Hydrocarbon`) and factories - **Jackson, Hannah**. Potentially will also be responsible for figuring out where to store constants (the original code has 400 lines of them!).
- 1 person to code the concrete derived classes (`Green`, `Blue`, `BtLSAF`, `JetA1`, `PtlSAF`) including overriding the `getFootprint()` function - **Grace**.

Testing will be performed using the Matlab outputs as the "base truth." Each person will code the tests for their own segment of the project.

Git Workflow

This development team has agreed to a formal workflow for managing version control. The workflow's primary objectives are to minimize the amount of work lost due to conflicts, provide a clear development history, and to instill good open-source programming practices in team members. A public repository on GitHub will hold official versions of the software and face outwards toward the open-source community. Pushing directly to this repository will be disabled and all updates will be handled via pull requests in GitHub. A private repository will be forked for the development team to work in collaboratively. Team members are to clone the private fork and not the public-facing repository when creating local repositories. The official repository will be set as an upstream, and team members will be notified when it is time to fetch new official versions. Team members, APC 524 AIs, and the APC 524 instructor will all be granted access to the private fork.

Branches will be named after the features they are used to develop with human-readable names. Team members are encouraged to check the list of existing branches on GitHub before pushing a new branch to origin. In addition to team members' feature branches, two primary branches will exist in the development fork: "dev" and "main". The dev branch is to be used for near-continuous committing and fetching. The idea is that this will allow team members to catch conflicts quickly, before they become difficult to resolve. The main branch will be updated using pull requests in GitHub and will only be updated with functioning features that pass all tests.

One team member (**Jackson**) will have the responsibility of handling pull requests and notifying team members when to fetch new official versions from main in the development fork or the upstream repository. They will also be responsible for coordinating merge conflict resolutions with the responsible authors should they arise. The proposed workflow is illustrated in Figure 2.

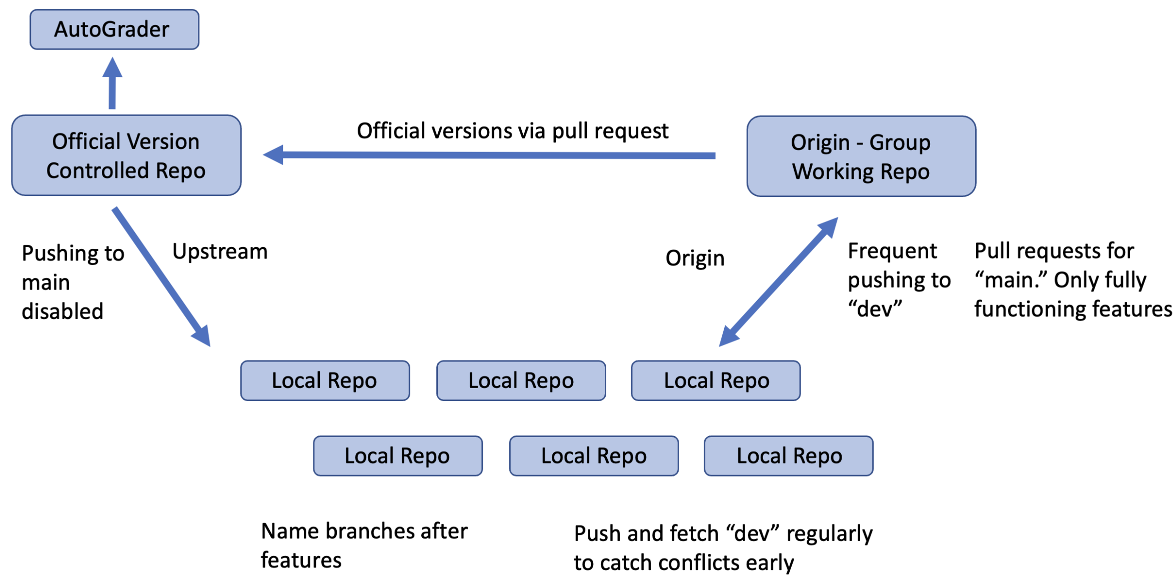

Figure 2: Proposed Git workflow

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